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Notes on the Modeling of Longitudinal Data

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November 1992

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U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES

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NOTES ON THE MODELING OF LONGITUDINAL DATA

CONTENTS

LIST OF FIGURES

NOTES ON THE MODELING OF LONGITUDINAL DATA

Introduction

This paper will briefly describe an individual differences growth curve approach to the modeling of longitudinal data. Initially, desirable properties of such a model will be presented. Next, the basic model and some simplifications will be described. Following this will be the data preparation step. Finally, this methodology will be applied to the Proteus Survey.

Schaie (1965) presented a general model for the study of longitudinal problems. In his model, Schaie noted the importance of separating the effects of age, time of measurement, and cohort. To this one could add that the approach should be psychologically focused, i.e., it should include person or individual parameters. Lastly, the method should be evaluateable via the current standards of statistical estimation and testing.

Individual growth curves methodology (Meredith & Tisak, 1990; Rao, 1958; Rogosa, Brandt, & Zimowski, 1982; Scher, Young, & Meredith, 1960; Tisak & Meredith, 1990; Tucker, 1958, 1966) has proven to be one enduring approach to the problem.

For development, consider the following longitudinal model:

$$y_i(t) = \sum_{j=1}^{r} w_{ij}\gamma_j(t) + \epsilon_i(t), \quad t \in \{1,2,\ldots,p\}, \qquad (1)$$

where

i is the ith individual; $i \in \{1,2,\ldots,N\}$
t is the tth time; $t \in \{1,2,\ldots,p\}$
$y_i(t)$ is a measurement on the ith individual at the tth time
$\epsilon_i(t)$ is the measurement error associated with the $y_i(t)$ observation
$\gamma_j(t)$ is the jth growth curve at time t
w_{ij} is the ith individual's salience or weight applied to the jth growth curve

In particular, (1) suggests that an individual's growth or decrement in a measured attribute over time, $y_i(t)$, may be decomposed into a set of subject weights or parameters, $\{w_{i1}, w_{i2}, \ldots, w_{ir}\}$, and associated growth or basis functions, $\{\gamma_1(t), \gamma_2(t), \ldots, \gamma_r(t)\}$. These curves, $\gamma_j(t)$, describe how *all* individuals change over time, i.e., the lawfulness of the group. They may be specified; e.g., they may be defined to be polynomials, i.e., $\gamma_1(t) \equiv 1$, $\gamma_2(t) \equiv t, \ldots, \gamma_r(t) \equiv t^{r-1}$, or they may be estimated as

parameters of the model. In this latter situation, they are nonparametric nonlinear functions. The individual differences coefficients, w_{ij}, model the i individual's weighting of the group curves, this approach permits individuality in the modeling of change. Since it is always possible to (perfectly) fit data by increasing the number of terms on the prediction side of the equation, for parsimony one is usually most interested in models where r is equal to 1 or 2. In sum, the approach allows usually nonlinear observed variates to be depicted by a variety of functions which include combinations of parametric/nonparametric and linear/nonlinear forms. With psychological variables, this flexibility is a great asset because usually there are little theoretical justifications for a definite form of growth, e.g., polynomial or exponential growth.

For a concrete illustration, let $r = 1$, $\gamma_j(t) = t$, and $w_{ij} = w_i$; then $y_i(t) = w_i t + \epsilon_i(t)$. Notice at the onset that this is a very simplified example which is intended for demonstration purposes only and which seldom models real growth. Figure 1 graphically represents the differentially weighted growth curve for the first, second, and n the subject. If the single curve, $\gamma(t) = t$, models the group's change, then the individual curves are a weighting of this function. In this case, w_i, may be viewed as a rate parameter with higher values depicting greater positive change over time and vice versa.

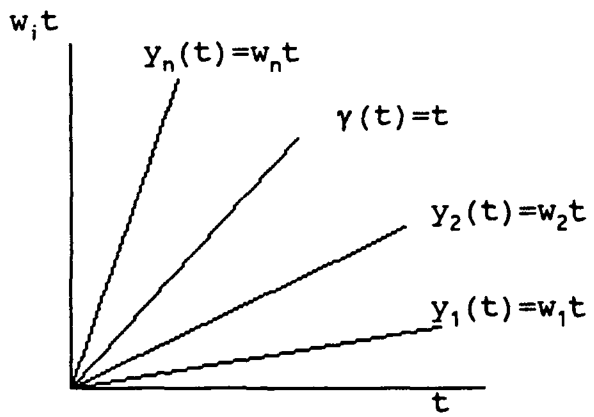

Figure 1. Differentially weighted growth curves.

A natural extension is to allow for different groups, populations, or cohorts by modifying (1) to

$$y_i^{(k)}(t) = \sum_{j=1}^{r} w_{ij}^{(k)} \gamma_j^{(k)}(t) + \epsilon_i^{(k)}(t),$$

where:

superscript k indicates the kth cohort; $k \in \{1,2, ...,m\}$.

Another enhancement is to allow for period or time of measurement effects. One may use either additive and/or multiplicative effects, i.e.,

$$y_i^{(k)}(t) = \tau_y(t) + \lambda_y(t) \sum_{j=1}^{r} w_{ij}^{(k)} \gamma_j^{(k)}(t) + \epsilon_i^{(k)}(t) \tag{2}$$

where the additive effect, $\tau_y(t)$, and the multiplicative effect, $\lambda_y(t)$, linearly influence the basic growth curve.

Equation (2) will be the basic model for the analysis of longitudinal data, because it entails all the desired criteria previously suggested. Further, we will see that by placing additional restrictions on the elements of the growth curves, i.e., $\gamma_j^{(k)}$, that these curves will span a period greater than the number of measurement periods. Also, notice that (2) may only be fully implemented with what Schaie (1965) has referred to as cohort sequential research designs.

One may write the first and second moments of (2) as

$$\mu_y^{(k)} = \tau_y(t) + \lambda_y(t) \sum_{j=1}^{r} \mu_{w_j^{(k)}} \gamma_j^{(k)}(t) \tag{3}$$

and

$$\sigma^{(k)}_{y(t)y(t')} = \sum_{j=1}^{r} \sum_{j'=1}^{r} \gamma_j^{(k)}(t) \gamma_{j'}^{(K)}(t') \phi_{jj'}^{(k)} + \sigma^{(k)}_{e(t)e(t')}, \tag{4}$$

where

$\phi_{jj'}^{(k)}$ is the covariance between $w_{ij}^{(k)}$ and $w_{ij'}^{(k)}$;
$\epsilon_i^{(k)}(t)$ does not covary with any of the $w_{ij}^{(k)}$ and
$\epsilon_i^{(k)}(t')$ when $t \neq t'$, i.e.,

$$\sigma^{(k)}_{e(t)e(t')} = 0.$$

A careful inspection of (2), (3), and (4), together with the subsequential assumptions, yields a factor analytic model with means (Harman, 1976; Mulaik, 1972). Computer programs, such as EQS (Bentler, 1989), LISREL (Jöreskog & Sörbom, 1989), and PROC CALIS in SAS (SAS Institute, 1989) which perform structural equations modeling (SEM) may be used to perform the statistical

analyses. The availability of these packages is given in Appendix A.

While numerous additional extensions are possible, one, which includes correlates of change (Rogosa & Willett, 1985), will be described next. Consider a simplification of (2) for this discussion only, i.e.,

$$y_i(t) = w_{i1} + w_{i2}\gamma_2(t) + \epsilon_i(t) \,. \tag{5}$$

In (5) w_{i1} can be considered the initial status of the individual on a measured attribute and w_{i2} can be considered the rate of change of the individual from the group or population longitudinal trajectory, $\gamma_2(t)$. For example, if $w_{i2} > 1$, then this individual changes at a rate greater than the group's. On the other hand, if $w_{i2} < 1$, then the converse it true. An interesting question is what correlates with w_{i2} or what are the "correlates of change"?

To answer this question in longitudinal research, one might formulate a growth curve model for a second variate, i.e.,

$$y_i'(t) = w_{i1}' + w_{i2}'\gamma_2'(t) + \epsilon_i'(t) \,,$$

in our simplified approach. The answer then becomes the correlation between w_{i2} and w'_{i2} or $\rho_{w_{i2}w'_{i2}}$. Clearly a variety of such structures is possible. More details are provided in Tisak and Meredith (1990).

Project Proteus

The methodology discussed previously was applied to the Proteus survey (Harris & Wochinger, 1992a, 1992b). In particular, two variables INTENT (intention to leave) and SUPPORT (how satisfied with support received from family/friends for military career) were modeled longitudinally. A total of 12 cohorts (gender by date of commission) formed the subpopulations. Two caveats are necessary: (1) The sample sizes for the female cohorts were small (16 to 31). (2) The scale underlying the INTENT variable changed from 1986 to 1987. For our purposes "beyond retirement" and "until retirement" in the 1987 questionnaire were treated as one category to conform with the 1986 survey. (See Appendix B for more details.)

The OLRDB data base (Hunter, Rachford, Kelly, & Duncan, 1987) exists as a SAS system file; therefore, a conversion to a raw file was necessary to provide input to the SEM program used,

i.e., LISREL 7 (Jöreskog & Sörbom, 1989). Furthermore, because the vector of means and the matrix of covariances are sufficient statistics for the analyses, they were computed and used as the raw data source. A series of 7 models were analyzed. For each of the two variates, these models were modifications of (2), i.e.,

$$y_i^{(k)}(t)=\tau_y(t)+\lambda_y(t)\,w_i^{(k)}\gamma^{(k)}(t)+\epsilon_i^{(k)}(t).$$

Model 1. Individual curves. A separate curve was used for each cohort.

$$\tau_y(t)=0;\ \lambda_y(t)=1$$

Model 2. Within gender analysis. A separate curve was used for each gender, but it was the same across all commission years.

$$\tau_y(t)=0,\ \lambda_y(t)=1,\ \gamma^{(1)}(t)=\gamma^{(2)}(t)=\ldots=\gamma^{(6)}(t),$$
$$\gamma^{(7)}(t)=\gamma^{(8)}(t)=\ldots=\gamma^{(12)}(t)$$

Model 3. 1-curve. One growth curve across all commission years and this curve was the same (invariant) for both genders.

$$\tau_y(t)=0,\ \lambda_y(t)=1,\ \gamma^{(k)}(t)=\gamma(t)$$

Model 4. 1-curve; multiplicative period effects. This was the same as Model 3 but multiplicative period effects were added.

$$\tau_y(t)=0;\ \gamma^{(k)}(t)=\gamma(t)$$

Model 5. 1-curve; additive period effects. This was the same as Model 3 but additive period effects were added.

$$\lambda_k(t)=1;\ \gamma^{(k)}(t)=\gamma(t)$$

Model 6. No cohort effects. Same as Model 3, but the cohort means were equated.

$$\tau_y(t)=0,\ \lambda_y(t)=1,$$
$$\gamma^{(k)}(t)=\gamma(t),\ \mu_w^{(k)}=\mu_w$$

Model 7. No growth. Same as Model 3, but the growth curve depicted no change with the years in service, i.e., it was flat.

$$\tau_y(t)=0,\ \lambda_y(t)=1,\ \gamma^{(k)}(t)=\gamma(t)$$

Note that as these analyses were primarily exploratory in nature, inadmissible estimates were permitted, i.e., in a few cases correlations greater than 1 occurred. For example in Model 3, Cohort 6 (females who were commissioned in 1985) had an inadmissible estimate for the correlation between intent and support of 1.133. Clearly a correlation of this magnitude is impossible. Although corrective actions are possible, i.e., constrained optimization which would keep the correlation between plus and minus one or a reparameterization of the model, these actions were not undertaken because it serves as a caveat that there were only 20 officers for this category and that further model developments are required.

The evaluations of these models were the chi-square and restricted chi-square tests (Appendix C). Models 1-3 became sequentially more constrained. Model 3 was considered an adequate fit (χ^2 (48) = 58.47, p = .143) and is not significantly different from Model 2. The use of either multiplicative or additive period effects (Models 4 and 5) did not improve the fit of the model. The test for cohort effects (Model 6) was significant as was the test for no change (Model 7). In conclusion, the structural equation modeling of the Proteus Project data yielded some very important results. For both the intent and support variates there were significant changes across time, i.e., these variables changed nonlinearly as a function of the number of years in the service. In particular, the longer that officers remained in the Army the less satisfied they were with the support that they received from family and friends. As illustrated in Appendix D, the decrease in support satisfaction is nearly monotonic. One might speculate that with increased demands placed on career officers that support members become less inclined to listen to "tales of woe." On the other hand, with increased years in service comes a descrease in the officers' intent to leave the service, i.e., the longer that an officer has been in the service; the longer that they intend to stay in the service. Of course, there is the natural confound that those who wanted out left the service and vice versa. Notice that with the use of this latent curve methodology, longitudinal functions were developed for a span of seven years from only two measurement periods, 1986 and 1987!

Another question of interest is that of cohort differences, i.e., after length of service has been controlled, are there any differences among the cohorts formed by gender and commission year date with respect to the mean rate of change? These means are statistically significant (Model 6) and are displayed in

Appendix D. In general, within gender, the earlier the date of commission the lower the mean rate of that cohort to leave the service and to be dissatisfied with family support. Since dissatisfaction with support apparently increases with years in the service and the mean of the 1980 cohort is lowest of the cohort means, is there a paradox? No, what is being suggested is that if *all* officers in the 1985 cohort were to remain in the Army for seven years, then on the *average* they would be predicted to have a greater intent to leave and would be more dissatisfied with support in comparison to the other cohorts.

Notice that period effects ($\tau_y(t)$ and $\lambda_y(t)$) were not significant. This implies that events between the 1986 and 1987 surveys were not influential. Further, after controlling for longitudinal change, the (disattenuated) correlations between dissatisfaction with support and intent to leave for the male cohorts were moderate (.372 to .494). These correlations are in a sensible direction; officers who receive less career support should be more inclined to leave that career and vice and versa. Probably because of low sample sizes the correlations for the female cohorts are rather varied and without any clear pattern.

There is however the warning that these were preliminary analyses and that refinements should follow, i.e., the original data should be carefully checked for outliers and more submodels should be inspected. Appendix D gives the estimates of all parameters in Model 3, the best model.

Additional considerations are the issues of stability, reliabilities, and cohort trajectories. As there is only one growth curve, strict stability (Tisak & Meredith, 1990) exists. That is, the model is consistent with no change in the rank ordering of individuals throughout their seven years in the service. Item reliabilities within cohort may be calculated as described in Tisak and Meredith. Finally, cohort trajectories may also be determined from (3).

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APPENDIX A

COMPUTER PROGRAMS

Structural Equation Modeling (SEM) computer packages available at the National Institutes of Health, Division of Computer Research and Technology, Bethesda, MD.

1. LISREL Release 7 (Jöreskog & Sörbom, 1989):
   - Stand alone
   - in SPSS 4.1

2. CALIS (SAS Institute, Inc., 1989):
   - SAS Release 6 Not available (Maybe 4th Qtr 1991)

3. EQS (Bentler, 1989):
   - BMDP Not available

References/Documentation:

Bentler, P. M. (1989). EQS structural equations program manual. Los Angeles: BMDP Statistical Software.

Jöreskog, K. G., & Sörbom, D. (1989). LISREL 7 user's reference guide. Mooresville, In: Scientific Software.

SAS Institute Inc. (1989). SAS/STAT user's guide, version 6, fourth edition, Volume I. Cary, NC: SAS Institute Inc.

APPENDIX B

COHORT SAMPLE SIZE

Survey Data: Project Proteus

Time of Measurement: 1986 and 1987

Sample Size:

	Date of Commission					
	1985	1984	1983	1982	1981	1980
Males	0148	0161	0142	0146	0181	0225
Females	0020	0023	0016	0022	0031	0020

Variates:

INTENT: Which of the following best describes your career intentions at the present time?

A. I plan to stay in the Army beyond 20 years. *(Added in 1987 survey.)*
B. I plan to stay in the Army until my 20 year retirement point.
C. I plan to stay in the Army beyond my obligation but am undecided about staying until retirement.
D. I am undecided whether or not I will stay in the Army upon completion of my obligation.
E. I will probably leave the Army upon completion of my obligation.
F. I will definitely leave the Army upon completion of my obligation.

SUPPORT: Using the scale below, indicate your level of satisfaction with each aspect at the present time. Support received from family/friends for a career in the military.

A. Extremely satisfied
B. Satisfied
C. Neither Satisfied nor Dissatisfied
D. Dissatisfied
E. Extremely dissatisfied

APPENDIX C

MODELS

1. Individual analyses

Cohort:	1	χ^2 (3) = 1.54, p = .672	
	2	χ^2 (3) = 3.45, p = .328	
	3	χ^2 (3) = 4.92, p = .178	
	4	χ^2 (3) = 11.47, p = .009	
	5	χ^2 (3) = 1.05, p = .789	
	6	χ^2 (3) = 1.18, p = .759	
	7	χ^2 (3) = 1.18, p = .757	ρ = 1.095
	8	χ^2 (3) = 5.20, p = .158	
	9	χ^2 (3) = 6.48, p = .091	not converged
	10	χ^2 (3) = 3.35, p = .341	
	11	χ^2 (3) = 6.00, p = .112	
	12	χ^2 (3) = 3.20, p = .362	

2. Within gender analysis: 1-curve

Males	χ^2 (18) = 23.61, p = .168
Females	χ^2 (18) = 22.64, p = .205

3. 1-curve χ^2 (48) = 58.47, p = .143

4. 1-curve: multiplicative period effects

χ^2 (46) = 58.51, p = .102

5. 1-curve: additive period effects

χ^2 (46) = 55.86, p = .151

6. 1-curve: No cohort effects in means

χ^2 (70) = 138.48, p = .000

7. 1-curve: No change over length of service

χ^2 (60) = 103.02, p = .000

Note: For all models inadmissible estimates were permitted for exploratory purposes, i.e., for some cohorts (e.g., females-1985) correlations were greater than 1.

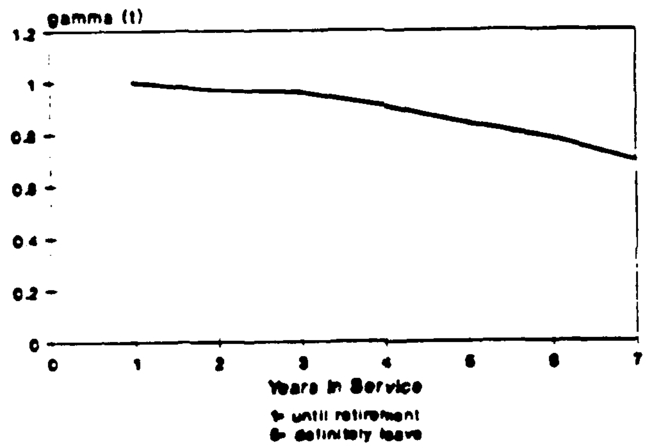
APPENDIX D

PARAMETER ESTIMATES

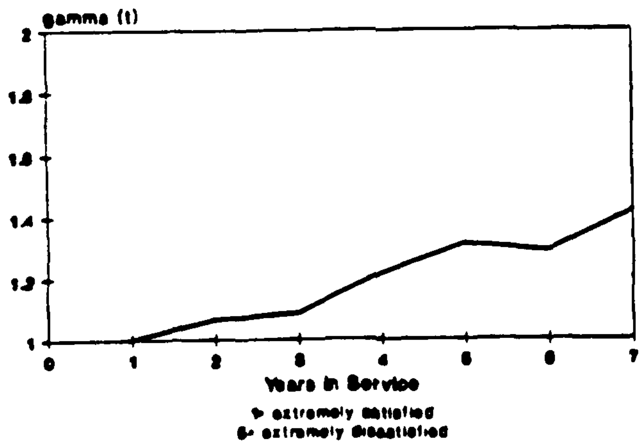
Gamma: growth curves

Years in Service	Intent	Support
01	1.000	1.000
02	0.968	1.064
03	0.962	1.085
04	0.907	1.213
05	0.839	1.310
06	0.782	1.288
07	0.695	1.416

Conclusion. Decline in intent to leave
with years in service



Conclusion. Increase in dissatisfaction
w/ support received from family/friends



APPENDIX D

PARAMETER ESTIMATES

Kappa: Cohort means for "rate" of change.

COHORTS Commission Date		Mean for INTENT	Mean for SUPPORT
Males	(1985)	2.646	1.940
Males	(1984)	2.692	1.882
Males	(1983)	2.468	1.646
Males	(1982)	2.035	1.434
Males	(1981)	2.012	1.432
Males	(1980)	1.999	1.283
Females	(1985)	3.071	1.424
Females	(1984)	2.779	1.759
Females	(1983)	2.327	1.633
Females	(1982)	2.266	1.351
Females	(1981)	2.249	1.318
Females	(1980)	1.411	1.216

Notes:

INTENT
1. until retirement
5. definitely leave

Bigger value means more intent to stay

SUPPORT
1. extremely satisfied
5. extremely dissatisfied

Bigger value means more dissatisfied

Note: These estimates are "after" length of service has been controlled.

APPENDIX D

PARAMETER ESTIMATES

Phi: Cohort "rate" variances and covariances.

COHORT		Variance INTENT Rate	Variance SUPPORT Rate	Covariance SUPPORT & INTENT Rate	Correlation (Disattenuated)
Males	(1985)	1.055	0.275	.266	.494
Males	(1984)	1.004	0.244	.226	.457
Males	(1983)	1.264	0.288	.251	.417
Males	(1982)	0.595	0.193	.134	.397
Males	(1981)	0.607	0.107	.095	.372
Males	(1980)	0.587	0.149	.115	.387
Females	(1985)	1.671	0.067	.380	1.133
Females	(1984)	0.634	0.633	.250	.395
Females	(1983)	0.146	0.243	.080	-.424
Females	(1982)	0.480	0.213	.169	.527
Females	(1981)	0.541	0.220	-.033	-.095
Females	(1980)	0.970	0.050	.015	.067

APPENDIX D

PARAMETER ESTIMATES

Theta Epsilon: Error (Unique) variances.

COHORT Commission Date		INTENT 86	INTENT 87	SUPPORT 86	SUPPORT 87
Males	(1985)	.262	.673	.750	.545
Males	(1984)	.376	.913	.577	.502
Males	(1983)	.486	1.077	.447	.442
Males	(1982)	.321	.648	.485	.501
Males	(1981)	.276	.516	.613	.459
Males	(1980)	.216	.393	.261	.447
Females	(1985)	.142	.822	.290	.560
Females	(1984)	.436	1.040	.179	.321
Females	(1983)	.375	.417	.366	.424
Females	(1982)	.209	1.107	.221	.565
Females	(1981)	.382	.652	1.133	.332
Females	(1980)	.554	.539	.284	.515